



RIGOROUS APPROACH IN InDA SOFTWARE SYSTEM FOR DEFORMATION DETECTION - CASE STUDY ON THE SMALL ENGINEERING STRUCTURE

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ABSTRACT

One of the main tasks in deformation monitoring is to investigate the movement or displacement that occurred to any structural object. The measuring techniques and the instruments used for such monitoring are categorized as geodetic and non-geodetic (i.e., geotechnical/structural) methods. A monitoring survey has been conducted in a laboratory to detect the deformation of a light weight concrete block which undergoes load testing. A number of target points on one surface of the concrete block have been monitored by triangulation survey using a total station. Five epochs of measurement have been obtained and each epoch was based on the load applied ranging from 0kN up to 358kN. Results from such testing indicate the practicality of the InDA Software System in deformation detection.

Keyword: Concrete block, network adjustment, deformation detection, displacement vector

1.0 INTRODUCTION

In general, the deformation measurement methods can be divided into two categories namely the geodetic and non-geodetic. The geodetic method of deformation monitoring of any structural object involves determining the coordinates difference of object points measured from a reference network. The non-geodetic method employs specialized instrumentation normally used by the geotechnical and structural engineers (Chrzanowski *et al.*, 1986; USACE, 2002; Szostak-Chrzanowski and Chrzanowski, 2008). The geodetic method is very useful in giving a global deformation picture of deformation. While the non-geodetic method is provide measurement data at point where locality is not a problem.

The main aim of geodetic deformations analysis includes (Chrzanowski and Szostak-Chrzanowski, 1995; Szostak-Chrzanowski *et al.*, 2005):

- i. Geometrical analysis, which describe the geometrical status of deformable object, change in shape and dimensions (rigid body movement) of whole deformable object with respect to a stable reference frame.
- ii. physical interpretation which describe the state of internal stresses and the relationship between the causative factors and deformations.

Nowadays, there are many rigorous approaches for deformation analysis via geodetic method. All these method has been proven for its applicability for example, congruency testing (Caspary and Borruta, 1987; Halim, 1995; 1997; Ranjit, 1999; Caspary, 2000) and Iterative Weighted Similarity Transformation (IWST) (Chen, 1983; Kuang, 1996; Szostak –Chrzanowski and Chrzanowski, 2008)

Recently, a deformation measurement has been conducted to a concrete block in conjunction with axial compression. The objective of the axial compression test is to find the strength of the concrete block in term of their load. In this axial compression test, strengthen of the concrete block measured using non-geodetic devices such as strain-gauge and linear displacement variable transform (LVDT). The result of non-geodetic is shows in term of strain –stress relationship (MokhtazulHaizad, 2003). The geodetic method was supported in this test is to calculate and visualize the displacement vector of the concrete block on each selected load. Visualization of the displacement vector is critical due to check the concrete block movement from the initial load until the block cracked.

This paper discusses the observation procedure in gathering the spatial information and the analysis of the concrete block with geometrical deformation. The study was supported by InDA software system (Khairulnizam&Halim, 2008; 2009) for data processing and analysis.

2.0 SOURCE OF DEFORMATION DATA – GEODETIC METHOD

The concrete block (**Figure 1**) used in this study has undergone an axial compression testing to determine its axial strength (MokhtazulHaizad, 2003). The axial compression experiment was performed by employing DARTEC testing machine (**Figure 2**). An incremental series of loads in kiloNewton (kN) standard were utilized in the testing ranging from 0, 200, 258 300 and 375 kN respectively.



Figure 1 Concrete Block

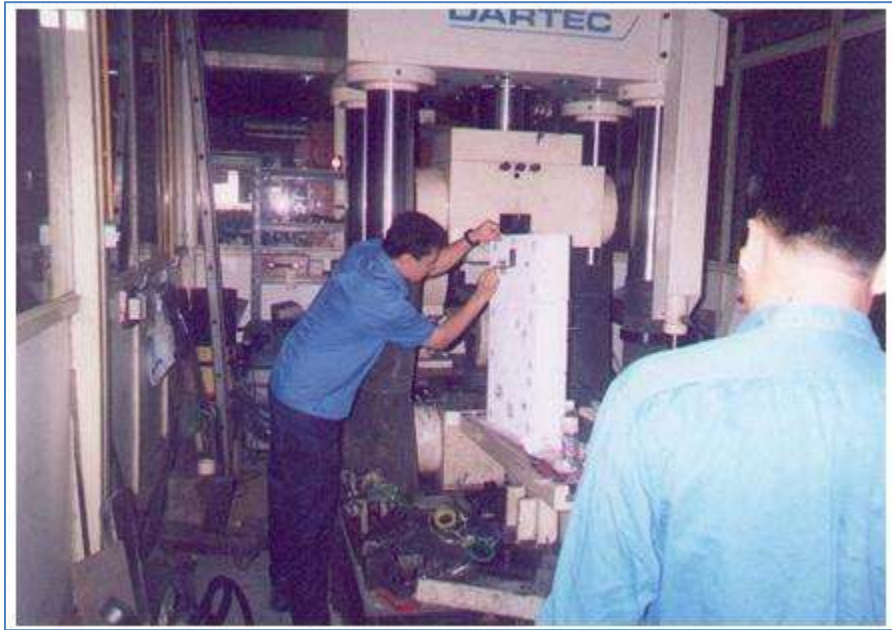


Figure 2 DARTEC Testing Machine

The geodetic method of deformation measurement was carried out from a small survey network established within the laboratory (**Figure 3**). A number of object points were identified and marked with retro-tape target and glued on one side of the concrete block (**Figure 4**). The survey method utilized a conventional 2D measurements consist of bearing and distance observed using Total Station. A total of five epoch of measurements were observed and each epoch was identified based on the load utilized during the testing (i.e., 0kN, 200kN up to 375kN).

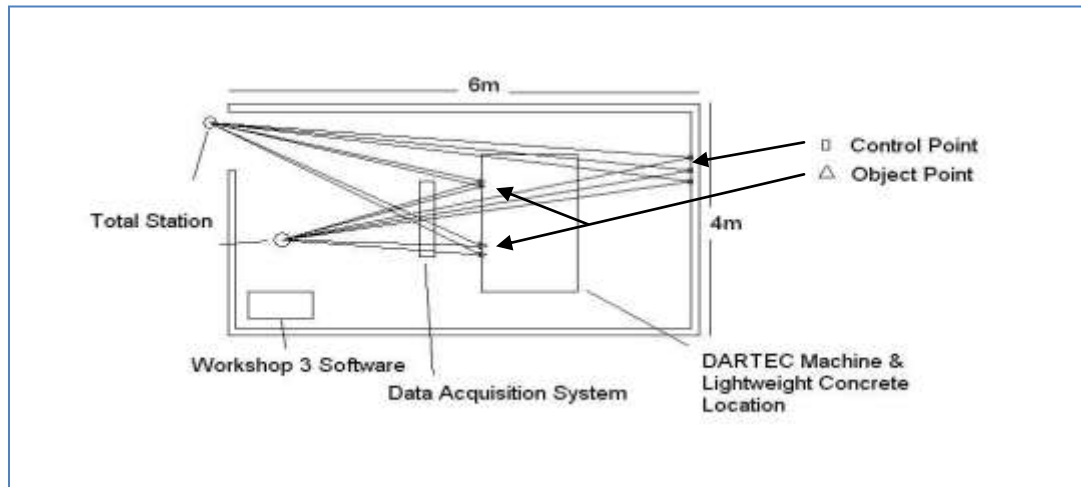


Figure 3 Sketch of the geodetic deformation network established in the laboratory

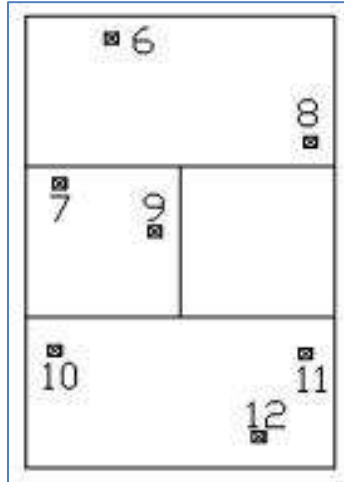


Figure 4 Distribution of object points on the concrete block

3.0 MATHEMATICAL FORMULATION

To process the deformation of the concrete block from geodetic observables, suggested two-epoch analysis used in this study. In practice, two-epoch analysis consisting of independent least square estimation (LSE) of a single epoch and geometrical detection of deformation between epochs (Halim, 1997).

3.1 NETWORK LEAST SQUARE ESTIMATION

The measured data (e.g., directions and distances) are being related to the parameter (coordinates) by mathematical relationship called the functional model and expressed as (Mikhail, 1975; Cross, 1985; Caspary, 2000; Ghilani and Wolf, 2005):

$$l = f(x) \quad [1]$$

where,

l is the vector of observations and
 x is the vector of parameter to be estimated.

Equation [1] generally is non-linear and it needs to be linearized using Taylor's theorem whereby the observation equation is written as:

$$\hat{v} = A\hat{x} + b \quad [2]$$

where,

\hat{v} is the vector of residuals,
 A is the design matrix,
 \hat{x} is the vector of corrections to the approximate value and
 b is the misclosure vector.

The normal equation with a full rank can be written as:

$$N\hat{x} + U = 0 \quad [3]$$

and solution for \hat{x} :

$$\hat{x} = -N^{-1}U = -(A^TWA)^{-1}A^TWb \quad [4]$$

where,

W is a weighted matrix

In general, least square estimation suffers from rank deficiency due to configuration or datum defect (Halim, 1997). As a solution, datum defect are overcome by means of constraints. Normally, the common choices of datum for the monitoring network are minimum constraint, minimum trace and partial minimum trace. In this particular work, the method of minimum constraint was chosen as datum definition.

3.2 GEOMETRICAL DEFORMATION DETECTION

The deformation detection required in this work was carried out by employing the Iterative Weighted Similarity Transformation (IWST) (Chen, 1983). To estimate the trend of the displacement vector, IWST is based on S-transformation as below (Chen, 1983; Kuang, 1996; USACE, 2002):

$$d^{(k+1)} = [I - G(G^T W^{(k)} G)^{-1} G^T W^{(k)}] d^{(k)} = S^{(k)} d^{(k)} \quad [5]$$

where,

k is the number of iterations

d is a displacement vector between estimated coordinate of all common points in the first epoch (\hat{x}_1) and second epoch (\hat{x}_2),

$d = \hat{x}_2 - \hat{x}_1$ S is a S-transformation matrix [6]

W is a weight matrix (with diagonal value of one for datum points and zero elsewhere).

$$G = \begin{bmatrix} 1 & 0 & 1 & 0 & \cdot & 1 & 0 \\ 0 & 1 & 0 & 1 & \cdot & 0 & 1 \\ y_1^0 & -x_1^0 & y_2^0 & -x_2^0 & \cdot & y_m^0 & -x_m^0 \\ x_1^0 & y_1^0 & x_2^0 & y_2^0 & \cdot & x_m^0 & y_m^0 \end{bmatrix} \text{ is an inner constraint matrix} \quad [7]$$

S-transformation (similarity transformation) or Helmert transformation is a useful tool in transforming the displacement vector (equation [6]) and its cofactor matrix. Computation of transforming the cofactor matrix is show as below (Halim, 1995):

$$Q_d = Q_{\hat{x}_1} + Q_{\hat{x}_2} \quad [8]$$

The main step in robust method is a forming the weight matrix, W . In the first transformation ($k = 1$) the weight matrix is taken as identity ($W^{(k)} = I$) for all common points. Then in the ($k + 1$) transformation the weight matrix is defined as (Chen, 1983; Kuang, 1996):

$$W^{(k)} = \text{diag} \left\{ \frac{1}{|d_1^{(k)}|} \right\} \quad [9]$$

Equation [9] is only applied on the common datum point. For example, either the reference point for a reference network or a group of point in a stable block for a relative network. Then, for object or non-datum points the weight is set as zero ($W^{(k)} = 0$). The iteration process continues until the absolute difference between the successive transformed displacements of all common points ($|d^{(k+1)} - d^{(k)}|$) are smaller than a tolerance value.

4.0 InDA Software System

A software system known as InDA (Industrial Deformation Analysis) has been developed by UTM-Photogrammetry and Laser Scanning Research Group (UTM-PLS), Universiti Teknologi Malaysia. InDA software system can handle real-time data acquisition using robotic total station

and on-site/off-line computation of geometrical form fitting and deformation analysis on the engineering or industrial structures. InDA software system consists three main modules, namely COMM, DAQ and ANALY as shown in **Figure 5**. The software system is written using Microsoft Visual C++ for COMM, DAQ and ANALY modules, whilst Microsoft Visual Basic 6 for component embedded in ANALY module.

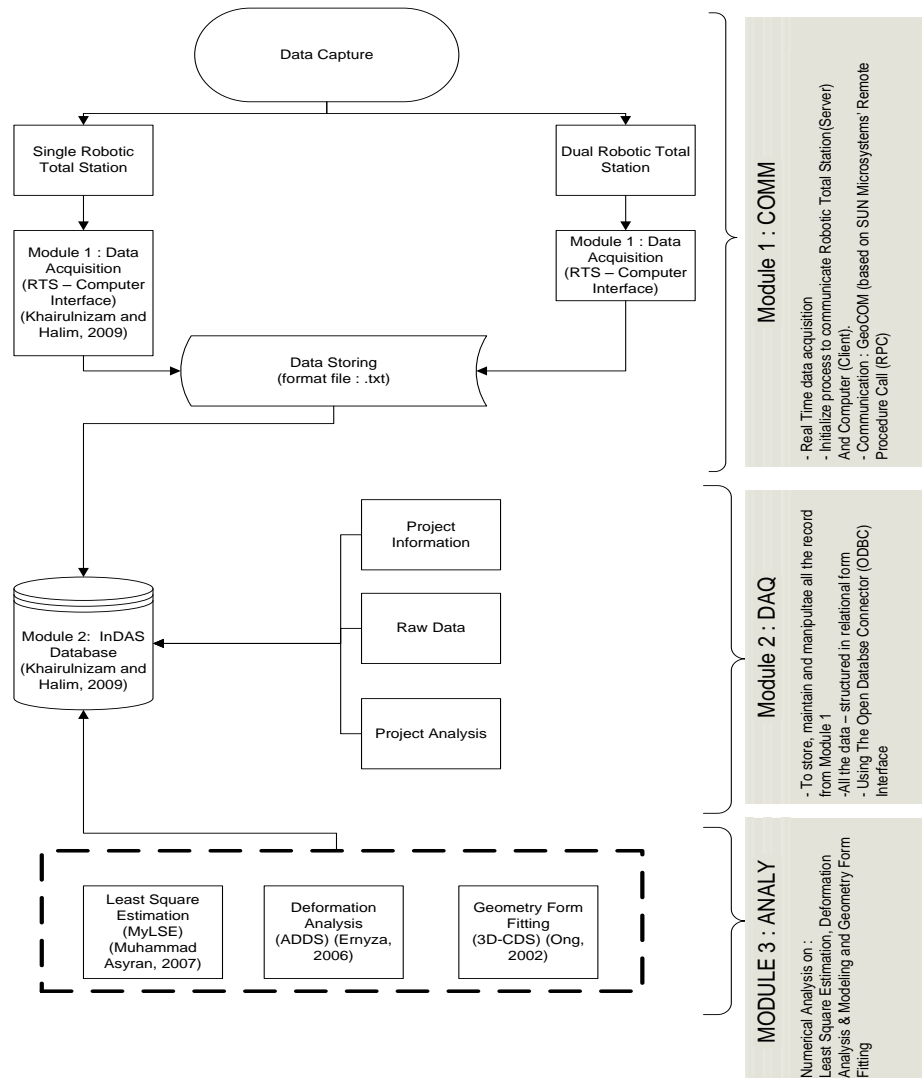


Figure 5 Configuration of InDA software systems.

In this paper, only ANALY module together with component embedded used to perform analysis on the deformation of concrete block. Component MyLSE is designed for multi-network adjustment (Muhammad Asyran, 2007). Component ADDS (Ernyza, 2007) is designed for deformation detection using IWST and can be applied on multi-dimensional deformation network. Component 3D-CDS (Ong, 2002) is developed for industrial geometrical form fitting analysis such as circle, flatness and plane parameters. Only MyLSE and ADDS components used in this paper for deformation data analysis and the analysis can be called as offline processing.

5.0 GEOMETRICAL INTERPRETATION OF CONCRETE BLOCK DEFORMATION

The observations campaign on the concrete block began with an epoch 1, where the concrete block are not subject to any charges or load and set as 0kN (kiloNewton). Then for next epochs, the concrete block were observed with regard to some phase of load is required as 200kN, 258kN, 300kN and 375kN. Rational in the selection phase of the load to be observed is to meet the objectives which the determination of concrete block in a vertical direction during the axial compression test is required by the engineer.

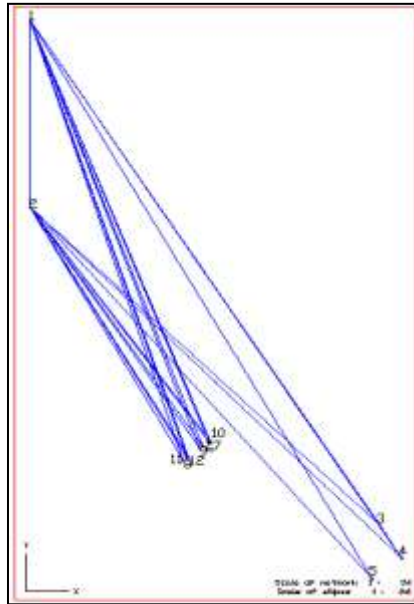


Figure 6 Monitoring network of concrete block

Thus, the monitoring network consists of 13 points (5 reference points (1,2,3,4 and 5) and 7 object points (6,7,8,9,10,11 and 12)) and composed of five epoch of observations. The monitoring network of concrete block is shown in **Figure 6**. Each measurement epoch consists of 22 directions and 15 horizontal distances. The summary of the least squares adjustment details are given in **Table 1**.

Table 1 Least squares estimation output

	0kN	200kN	258kN	300kN	375kN
Datum Definition	X_1, Y_1	X_1, Y_1	X_1, Y_1	X_1, Y_1	X_1, Y_1
Datum Defect	2	2	2	2	2
No of Observation	37	37	37	37	37
No of Degree of Freedom	15	15	15	15	15
No of Iteration	2	3	3	3	3
Variance a Posteriori	0.4357	0.4577	0.3842	0.5513	0.4747
Global Test	$0.238 < 1 < 1.04$	$0.250 < 1 < .09$	$0.210 < 1 < 0.92$	$0.301 < 1 < 1.32$	$0.259 < 1 < 1.13$
Local Test	Lulus	Lulus	Lulus	Lulus	Lulus

For additional, 375kN load imposed on the concrete blocks in visual attention that there are significant or substantial cracks on the object. Further, studies on the deformation of concrete blocks with the observations set at no load (0kN) as a reference epoch. Thus, other expenses compared to the reference epoch, such as forming joint 0kN vs. 200kN, 0kN vs. 258kN, 0kN vs. 300kN and 0kN vs. 375kN.

Significant level for deformation analysis was chosen as 0.05. The tolerance value was taken as 0.0001meter. The IWST method converged at the fourth iteration and verified points 6 to 12 as moved since load of 200kN. The result of IWST processing is scheduled in **Table 2**.

Table 2 IWST test result on each load combination

	0kN & 200kN	0kN & 258kN	0kN & 300kN	0kN & 375kN
Pooled Variance Factor	0.4467	0.41	0.4935	0.4552
Variance Ratio Test	1.050<2.405	1.1.34<.405	1.265<2.405	1.089<2.405
Stable Points	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5
Moved Points	6,7,8,9,10,11,12	6,7,8,9,10,11,12	6,7,8,9,10,11,12	6,7,8,9,10,11,12

The result of displacement vector as shown in **Table 3** reflect the occurrence of a significant movement in the concrete blocks from the load 0kN vs. 258kN, about 1cm at points 10, 11 and 12. Then, the displacement vector decreases and consistence, between 3mm to 9mm when load of 0kN vs. 300kN and 0kN vs. 375kN. **Figure 7** shows the failure or cracking of the surface of concrete block at load 0kN vs. 258kN and **Figure 8** shows the displacement vector for each load combinations.

Table 3 Displacement Vector

Control Points	Load Combinations (in meter)			
	0kN & 200kN	0kN & 258kN	0kN & 300kN	0kN & 375kN
1	0.0014	0.0014	0.001	0.0005
2	0.0008	0.0009	0.0006	0.0003
3	0.0008	0.0007	0.0004	0.0001
4	0.0007	0.0006	0.0005	0.0002
5	0.0006	0.0008	0.0008	0.0004
Concrete Block Points				
6	0.001	0.0012	0.0031	0.0011
7	0.0025	0.0026	0.0053	0.0044
8	0.0041	0.0065	0.0080	0.0093
9	0.0046	0.0047	0.0083	0.008
10	0.0012	0.0121	0.0046	0.0026
11	0.0012	0.0118	0.0037	0.0039
12	0.0044	0.0173	0.0080	0.0075

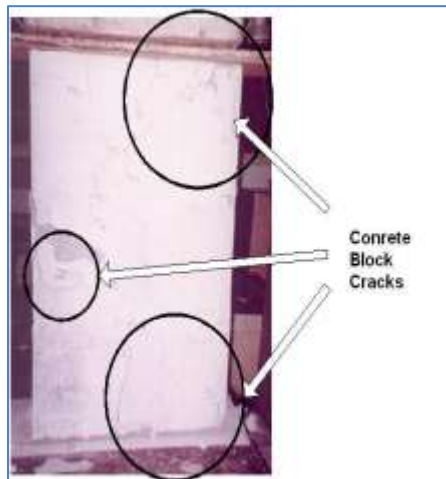


Figure 7 Cracking of the concrete block (at load 0kN vs. 258kN)



Scale of network 1 : 45
Scale of deformation and ellipse 1 : 31

Figure 8 Graphical interpretation of displacement vector

6.0 CONCLUSION

The software system is a fully automated in data acquisition. For data processing and analysis, user still able to process and calculated the final result at field or “on-site solution”. The ability of surveyors to provide other profession such as civil engineer, a graphical presentation of displacement vector of the monitoring object is very meaningful. For example, results of this particular monitoring works (**Figure 9**) were given to civil engineering colleagues. Such results will then enable them to visualize the movement trend of the lightweight concrete block which undergone the axial compression testing.

Theoretically, due to axial compression the lightweight concrete will expand in the way shown graphically in **Figure 10** (picture A). On the other hand, if the movement of the concrete block occurs as in picture B it implies that either the geodetic monitoring results was wrong, or there could be wrong designing of the concrete block or mislaid the concrete block on the DARTEC machine are questionable. Therefore, the results obtained in this work are agreed to what is expected.

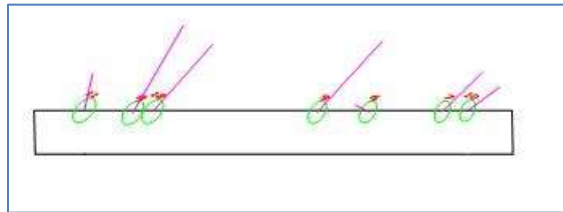


Figure 9: Displacement vector of object points on the concrete block (0kN vs. 375kN)

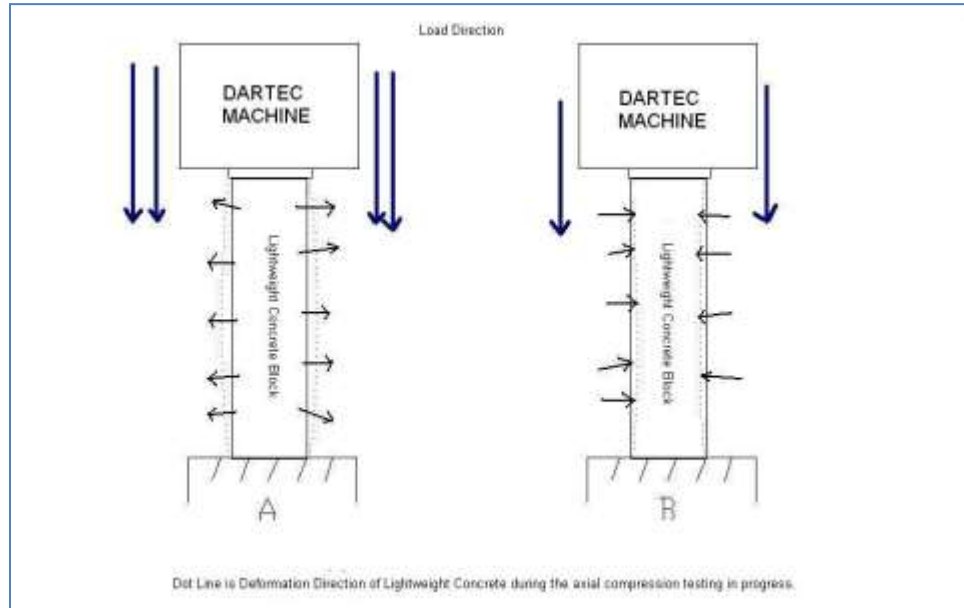


Figure 10: Direction of concrete block during the test

ACKNOWLEDGEMENT

The authors acknowledge financial assistance for this research from Ministry of Science, Technology and Innovation (MOSTI) for National Science Fellowship (NSF) and e-Science Fund (Vot 79141).

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